C. J. Lapp

A Graphic Study of Sound Waves

A GRAPHIC STUDY OF SOUND WAVES EMITTED BY SINGING TUBES

BY

CLAUDE JEROME LAPP

A. B. Albion College, 1917

THESIS

Submitted in Partial Fulfillment of the Requirements for the

Degree of

MASTER OF ARTS

IN PHYSICS

IN

THE GRADUATE SCHOOL

OF THE

UNIVERSITY OF ILLINOIS

1920

UNIVERSITY OF ILLINOIS

THE GRADUATE SCHOOL

February 10 1920

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY CLAUDE JEROME LAPP

ENTITLED A GRAPHIC STUDY OF SOUND WAVES EMITTED BY SINGING TUBES

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ARTS IN PHYSICS

Chas. T. Knipp
In Charge of Thesis

A. P. Carman
Head of Department

Recommendation concurred in*

Committee on Final Examination*

*Required for doctor's degree but not for master's

TABLE OF CONTENTS

INTRODUCTION

In December, 1917, while making a liquid air trap from Pyrex glass tubing, Professor C.T. Knipp noted that the trap when heated in a certain spot emitted a distinctly audible tone. It was also found that by constructing the trap with certain proportions the tone could be increased so that a sound of large intensity could be produced. It was soon recognized that this source of sound had many possibilities, among which was the possibility that it might be used as a new standard of sound. This presupposed that the sound emitted was a pure tone which could only be substantiated by an analysis of its wave form. The work presented in this paper is such an analysis.

METHODS USED

It was decided after reviewing the different possible methods of sound wave analysis to use two independent methods, doing the major portion of the work by one method and using the other as a check. The check method employed was to analyze by an oscillograph, a telephone electric current upon which the sound waves had been superimposed. The method used for the major portion of the work employed a diaphragm which, when set in vibration by a sound wave, caused a mirror to vibrate which in turn reflected a beam of light to a moving photographic plate.

APPARATUS USED

The apparatus employed by the two methods was as follows:

First Method:

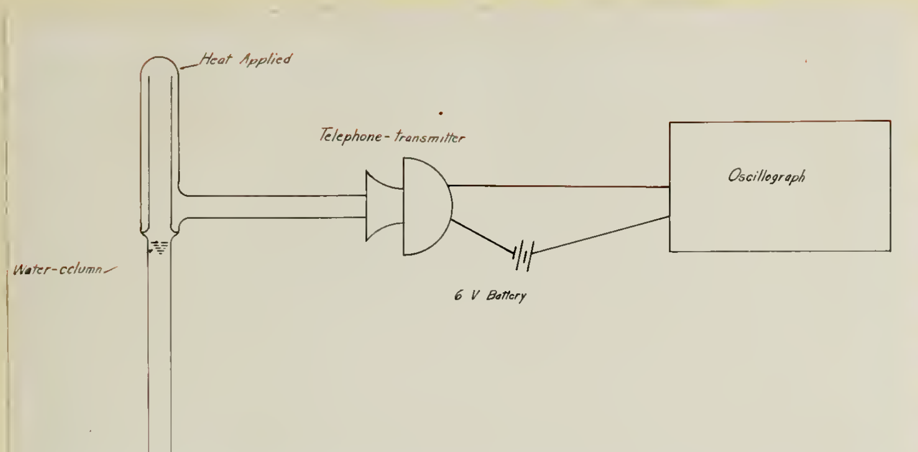


Fig. 1

The sound was emitted from the sounding tube into a telephone transmitter, the circuit of which, containing a 6 volt storage battery, was connected to the oscillograph. The circuit outside the telephone was carefully made with neither inductance nor capacity. The inductance in the transmitter was necessarily very small or equal to zero. The oscillograph, type E.M. Form C No.181819, manufactured by the General Electric Company, contained an analyzing element of extremely high sensitivity. This element would probably detect vibrations up to 8000 or 10000 per second, and hence this apparatus should then be able to determine the form of any wave that the transmitter diaphragm would pick up.

<u>Second Method</u>: This method was suggested by the principle employed by Professor D.C. Miller in his phonodeik. The optical reflecting system, however, was entirely different, being at the same time much simpler. The diaphragm of dermatype paper was stretched over a two inch circular opening in a brass plate, 0.159 cm. in thickness and held in place by a flat brass ring of the same thickness screwed to the plate. To the center of the diaphragm was

[illegible]

[illegible]

attached perpendicularly four or five silk fibers, the other end of which was held by a very fine conical aperiodic spring. Across the diaphragm, 0.476 cm. above and parallel to it, was very tightly stretched one strand of a three strand silk thread. This was passed 0.154 cm. from the perpendicular fibers. A small mirror 0.0435 cm. in width and 0.154 cm. long was mounted with its plane parallel to the diaphragm between the horizontal silk strand and the vertical silk fibers. When a sound wave was caught by the diaphragm the mirror vibrated with it around the horizontal silk strand, causing a beam of light to vibrate and trace out the sound wave form on a moving photographic plate.

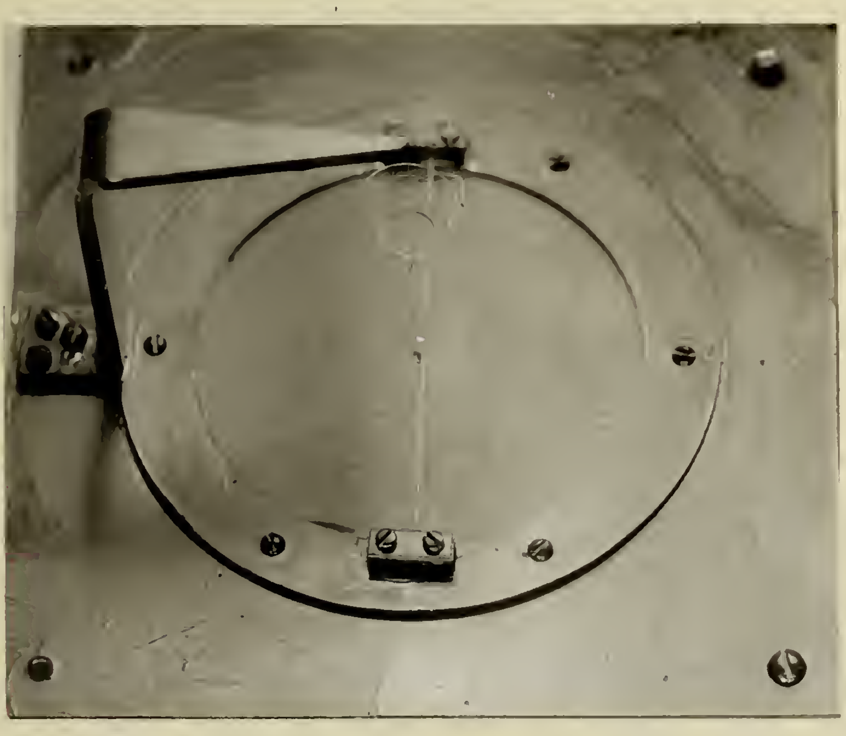


Fig. 2

F.A. Shultze* has shown that paper is aperiodic and that a paper diaphragm is sensitive to sounds of any wave length. The dermatype paper used was taken from dermatype stencils manufactured

*Annalen d. Physik IV, Folge, Vol.24, p 785, 1907.

for the Edison-Dick mimeograph. This paper is flexible, and very strong.

In the diaphragm mounting the author has incorporated some new features which are shown in Figures 2 and 3. No horn or resonating device of any sort was used in any of the work to increase the intensity of the sound brought to the diaphragm. Professor Foley of the University of Indiana read a paper before the St. Louis meeting of the American Physical Society in December, 1919, in which he clearly demonstrated the distorting effects of bent tubes and straight horns on sound waves. Although this diaphragm mounting was designed before Professor Foley's paper was read, the author was very careful in the designing to avoid air pockets of any sort.

The inertia of the moving parts of the mounting is probably smaller than that of any diaphragm mounting heretofore used in sound wave analysis. The only masses involved are, the mass of three or four silk fibers 3 cm. long, the mass of the mirror 0.154 cm. long, 0.0435 cm. wide and of microscopic thickness, and the mass of the small specks of shellac used to mount the mirror.

The spring used was made by winding No. 40 steel wire on a brass cone of small dimensions. The period of any spring is a function of its diameter and the elasticity of the material used. The diameter of each turn of wire was different from that of any other, therefore each turn had a different period and the spring as a whole was aperiodic. While in use a small tuft of cotton was placed inside the spring to damp out sidewise vibrations.

The other details of the set-up may be easily seen from the diagram, Figure 3.

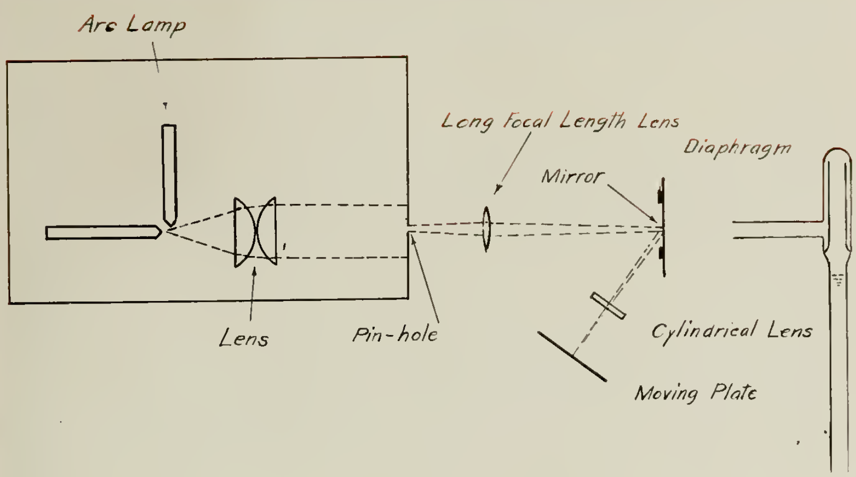
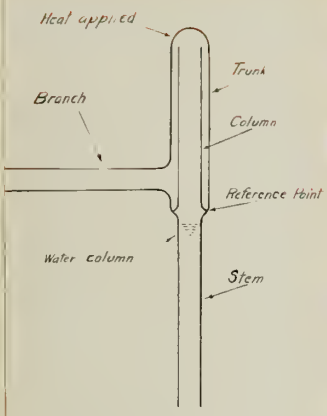


Fig. 3

In this work three types of cameras were used. In one, a gun camera, a photographic plate held in a steel holder was fired across a slit at about ten feet per second; the second, a falling plate camera, caused the plate to fall by a slit at the rate of fourteen feet per second; while the third, a drum camera, operated by a motor at any speed desired, took a film of any length up to sixty inches.

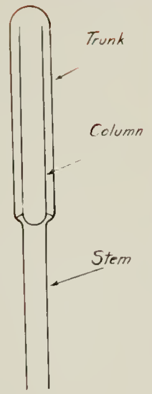
EXPERIMENTAL WORK

The singing tubes used were of two forms, the straight form and the L form. Figure 4 shows the L-form and the nomenclature applied to the various parts as has been used in this paper. Figure 5 shows the straight form in a like manner. The L-form has a water column the height of which was measured from the ring-seal below the branch. All distances above this reference point have been taken as negative and all distances below as positive.



Sounding Tube "L" form

Fig. 4



Sounding Tube Straight Form

Fig. 5

In a paper read before the St. Louis meeting of the American Physical Society, December, 1919*, Professor Knipp stated that Fig. 6 represents the operating condition in the L-form of the singing tube. If this is the case in the L-form, then obviously the operating condition in the straight form is as represented in Figure 7.

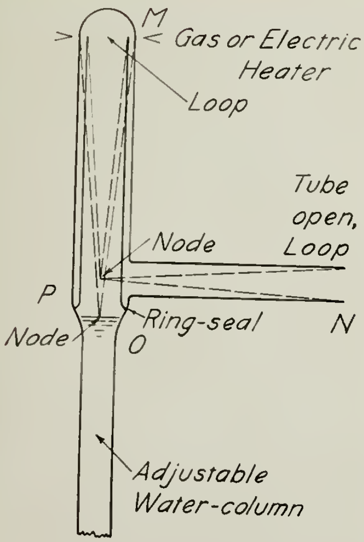


Fig. 6

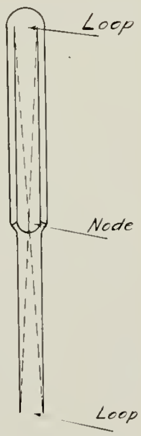
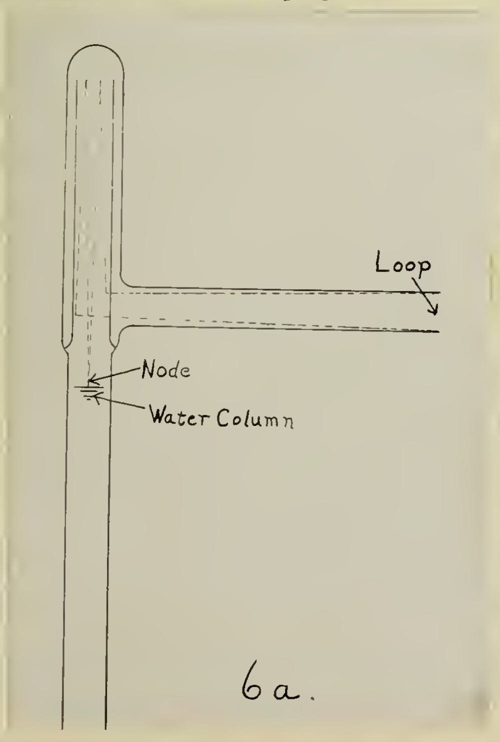


Fig. 7

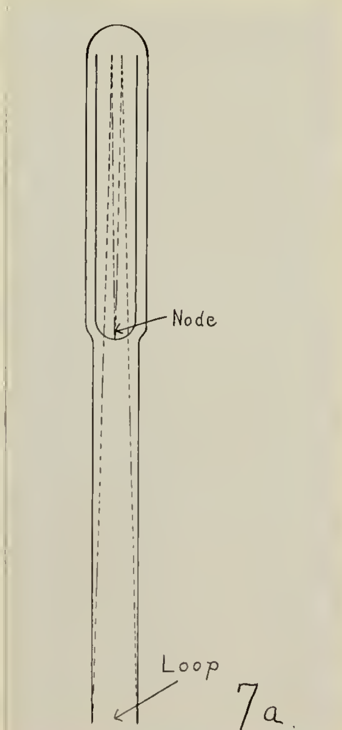
* "A Possible Standard of Sound,- I Study of Operating Condition". Read before the Am. Phys. Soc., St. Louis, December 1919.

While computing from this theory the wave length given by a tube of the straight-form (tube No. 5), the author noted a great discrepancy between that length and the length actually given. Computation was then made of the wave length given by both types of tubes from oscillograms on which had been placed beside the sound wave, an alternating voltage wave of known frequency. It was found in each case that what had heretofore been supposed to be a half wave length was less than one quarter wave length. In the straight-form the length of the tube plus the length of the column represented <u>one quarter wave length</u>, while in the L-form the length of the branch plus twice the length of the trunk plus the reading of the water column gave, with end corrections, one fourth wave length.

The operating condition must then be represented by Fig. 6a and 7a, instead of Figure 6 and 7. This new theory is further substantiated by other experimental data previously taken by Professor Knipp and his students, and heretofore unexplained, which will not be discussed in this paper.



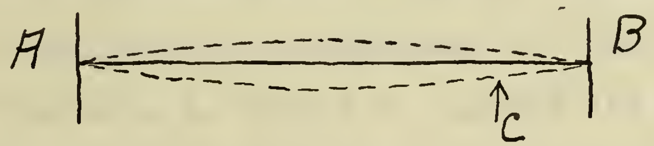
6a.



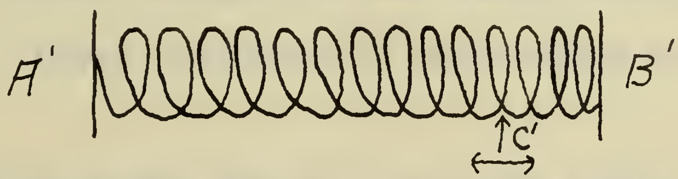
7a.

The value of any theory is determined by the accuracy of predictions made from it; and although it is not the object of this paper to explain why the tubes sound, the author has been interested in determining some of the consequences of the new operating conditions just set up. As was previously known, a change in the height of the water column, or water piston, produced a change in the pitch of the tone emitted. It had also been determined that for either type, the tube "to sound its fundamental with ease must have definite lengths as regards the various vibrating columns."

For more definiteness, let us consider the following analogies. Suppose we take a wire stretched between two rigid supports A and B, having properties such that when it is plucked it will form a standing wave of one half wave length. We know that there exists



some position C such that if pressure is exerted with correct periodicity, a standing half wave will be formed in the wire. At least one position for C can be determined so that the standing wave will be formed with a minimum expenditure of energy. Again, we might consider a spring stretched between two rigid supports, A' and B', having properties such that if it was energized at a point C' by a



horizontal motion of correct periodicity, a standing compressional wave of one half wave length would be set up. Here again, at least one position of C' might be located so that the wave would be formed

[illegible]

[illegible]

$$[illegible]$$

[illegible]

$$[illegible]$$

[illegible]

with a minimum expenditure of energy.

The above is analogous to what happens in the singing tube. The standing wave of one fourth wave length inside the tube should have <u>at least one position</u> analogous to the positions C and C', where the wave can be maintained with a minimum expenditure of energy. It is probable that more than one such point exists. According to Euler's Principle of Least Action,

$$\int_{t_0}^{t_1} \delta (L\, dt) = 0,$$

where L is the kinetic energy at any time, and $(t_1 - t_0)$ is the period of the system, all phenomena in nature takes place with a minimum expenditure of energy. Due to the fact that the position of energy supply is fixed, the quarter wave length inside the tube adjusts itself by end corrections, so that the energy supplied will come at one of the points corresponding to C and C'. We would expect then, as the tube is forced to change its wave length to find positions of the water piston where the strained end correction of the wave would require, to produce further variation, more energy than would be necessary to change the wave to a new length, where the energy supply would occupy a position of minimum expenditure, different from the one it previously occupied. A standing wave of changing length in stable equilibrium would then become unstable at a critical point, change its wave length entirely, and become stable again. These conditions of equilibrium have been found in practice.

It is also known that an open organ pipe will emit a pure tone if it is blown gently, and that overtones appear when the pressure is increased. We should expect to find the same effect in

the singing tube as the energy supply is augmented. This effect has been noted and will be discussed later.

Resonators were used in some of the work (See Fig. 8) to increase the volume of the tone.

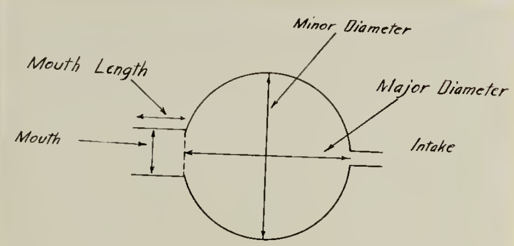


Fig. 8

Nearly two hundred photographs of the wave form of the sound emitted by these two types of singing tubes have been taken. The most representative of these have been selected and divided into series which will be discussed in order. The wave lengths given were computed for temperature at 20°C.

The data in the following three tables give the conditions under which the photographs were taken, and the dimensions of the tubes and resonators used.

TABLE OF PHOTOGRAPHIC DATA

Photo No.	Form of Tube	No. of Tube	Height of Water Column* in cm.	Reso- nator	Method of Photog- raphy	Camera Used	Number of Burner	Series
*1	L	5	+23.0	-	2	F.P.	1	5
6	B	4	- 4.0	-	1	Drum	2	9
13	B	5	-	-	1	Drum	2	9
15	L	4	0.0	1	1	Drum	1	9
18c	B	4			2			
21	B	4	- 5.0	-	2	F.P.	1	
22	Organ Pipe							
25k	B	9	+12.0	10	2	Drum	1	4
26	Organ Pipe				2			
28b	Organ Pipe				2			
32a	L	5	none	-	2	F.P.	1	5
34c	L	5	+14.0	-	2	F.P.	1	5
35c	L	5	+20.5	-	2	F.P.	1	5
37a	L	5	none	11	2	F.P.	1	7
37b	L	5	+ 7.5	11	2	F.P.	1	7
37c	L	5	+19.0	11	2	F.P.	1	7
38a	B	9	+ 1.0	12	2	F.P.	1	3
38b	B	9	- 4.0	12	2	F.P.	1	3
38c	B	9	+ 6.0	12	2	F.P.	1	3
39a	B	9	- 6.0	12	2	F.P.	1	3
39b	B	9	+13.0	12	2	F.P.	1	3
39c	B	9	+18.0	12	2	F.P.	1	3
43	B	21	+11.3	-	2	F.P.	2	2
44	B	21	+ 1.0	-	2	F.P.	2	2
46	B	21	+23.0	-	2	F.P.	2	2
47	B	21	+15.2	-	2	F.P.	2	2
53	B	21	+15.8	-	2	F.P.	2	2-1
54a	B	21	- 3.2	-	2	F.P.	1	8
54b	B	21	- 3.2	-	2	F.P.	1	8-1
58	L	14	-	-	2	F.P.	1	6
59	L	14	-	-	2	F.P.	2	6
A	Organ Pipe			-	2	F.P.	-	10
B	(One L-form		-	-	2	F.P.	1	10
C	(One St-form							
C	Two L-tubes		Max. Volume	10 & 1	2	Drum	1	10
D	As in C		Fewer Beats	10 & 1	2	Drum	1	10
E	As in D plus high pitch organ pipes			10 &1	2	Drum	1	10
F	Three Organ Pipes			-	2	F.P.	-	10
G	French Horn		-	-	2	F.P.	-	10

* Length of Extension Used in Case of Straight Tube.

TABLE II

TABLE OF DIMENSIONS OF THE SINGING TUBES USED

Measurements in Millimeters

Tube	Type	Trunk			Branch		
		Length	Inside Diam.	Outside Diam.	Length	Inside Diam.	Outside Diam.
2	Branch	124	17.0	19.0	115	8.5	11.0
4	Branch	118	14.4	16.4	155	8.5	11.0
5	Long	93	22.5	24.5	-	-	-
14	Long	114	23.0	25.0	-	-	-
9	Branch	116	17.0	19.0	135	9.7	11.7
21	Branch	133	18.0	20.0	144	10.0	12.0

Tube	Type	Trunk			Branch		
		Length	Inside Diam.	Outside Diam.	Length	Inside Diam.	Outside Diam.
2	Branch	112	9.5	12.0	200	8.5	11.0
4	Branch	109	9.5	12.0	211	8.5	11.0
5	Long	81	16.0	18.0	133	16.5	18.5
9	Branch	105	12.0	14.0	230	9.7	11.7
14	Long	97	17.0	19.0	159	15.0	17.0
21	Branch	122	12.0	14.0	235	10.0	12.0

TABLE III

TABLE OF DIMENSIONS OF RESONATORS USED

Measurements in Millimeters

Mumber	Mouth Length	Mouth Inside Diam.	Minor Diam.	Major Diam.	Intake Length	Intake Inside Diam.	Kind of Glass
1	53	51	115	122	31	10	Soda
3	50	48	90	93	31	10	Soda
10	61	27	142	148	33	14	Pyrex
11	50	55	122	115	13	10	Soda
12	-	25	680	25	12	14	Pyrex

[illegible]

[illegible]

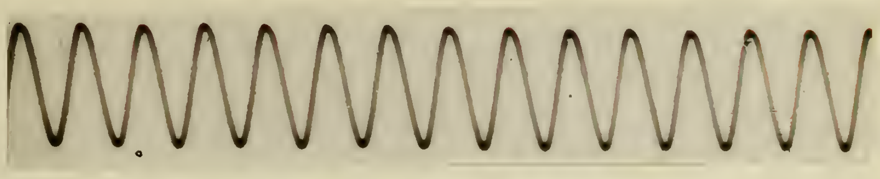
[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Series I

L-Form, Without Resonators, One Burner

18c

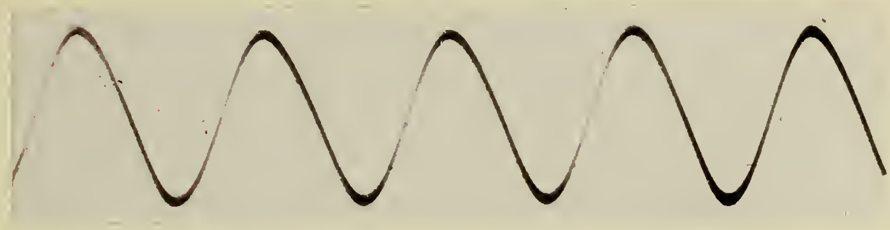


λ = 152 cm.

54b

λ = 148 cm.

53



λ = 220 cm.

The curves represent the wave forms of sounds emitted by the L-form of singing tubes when they were producing their tones with ease. The heat energy was being supplied by one ring-burner. The wave lengths were: l_{18c} = 152 cm., l_{54b} = 148 cm., l_{53} = 220 cm.. The water columns were adjusted to -5 cm., -3.2 cm., +15.8 cm., respectively. Wave 18c was taken with tube No. 4. The wave length appears much shorter than the others because of a slower movement of the photographic plate on which it was taken. A careful examination of the curve shows a suggestion of an overtone to the immediate right of the peak. This disturbance is almost identical with the one to be presented in Professor Miller's photograph No.

[illegible]

[illegible]

[illegible]

$$[illegible]$$

[illegible]

$$[illegible]$$

[illegible]

[illegible]

[illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]

2260 in Series XI. The wave 54b is a pure sine wave and wave 53 is very nearly pure. A close examination of 53 will show a fullness to the lower right of the peak of each maximum. These waves show that it is possible for the L-form of tube to produce a pure tone when the vibrating columns are correctly adjusted and the energy is not being supplied too rapidly. They also indicate that for a pure tone the energy should be supplied near the node. For curve 54b the energy was supplied 9 cm. from the node and 27 cm. from the loop, while in 53 the same two distances are 28 cm. and 27 cm. respectively. Curve 54b shows the presence of a cylindrical lens in the apparatus arrangement.

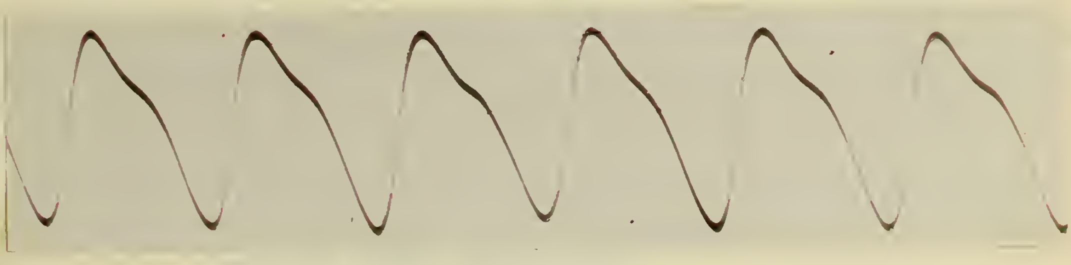
Series II

L-Form, Without Resonators, Two Burners

46

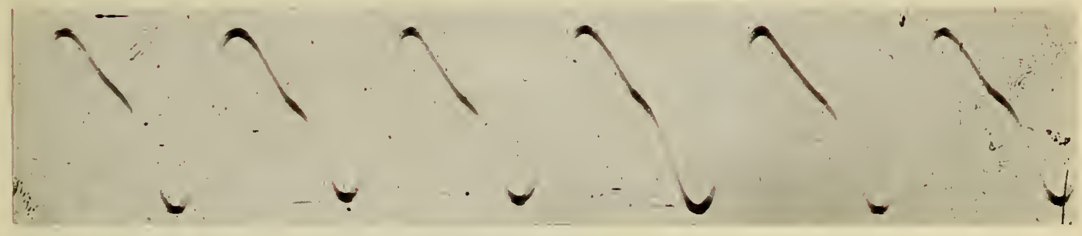
λ = 252 cm.

47



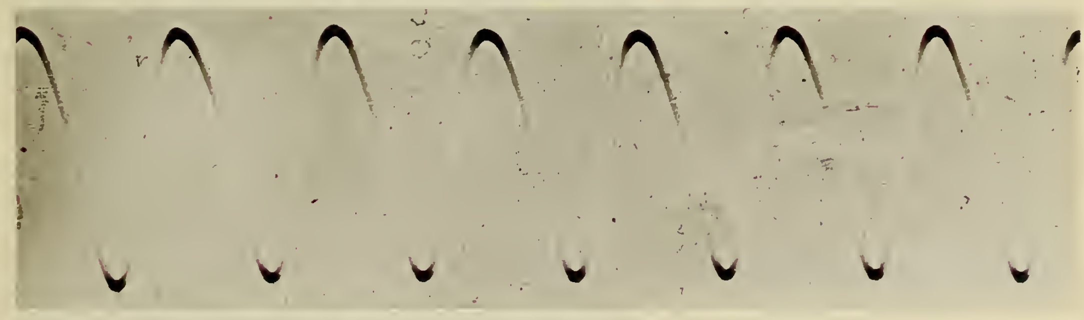
λ = 220 cm.

43



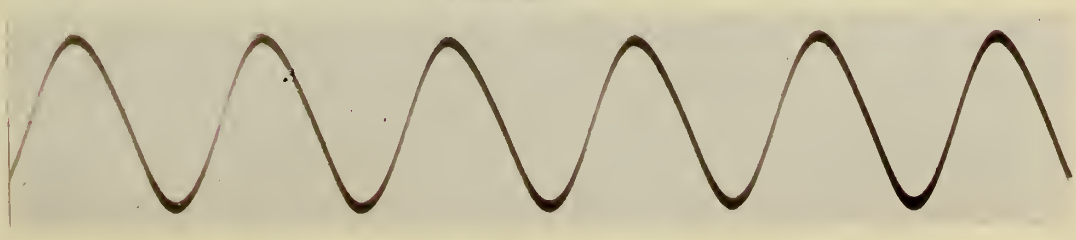
λ = 205 cm.

44



λ = 164 cm.

53

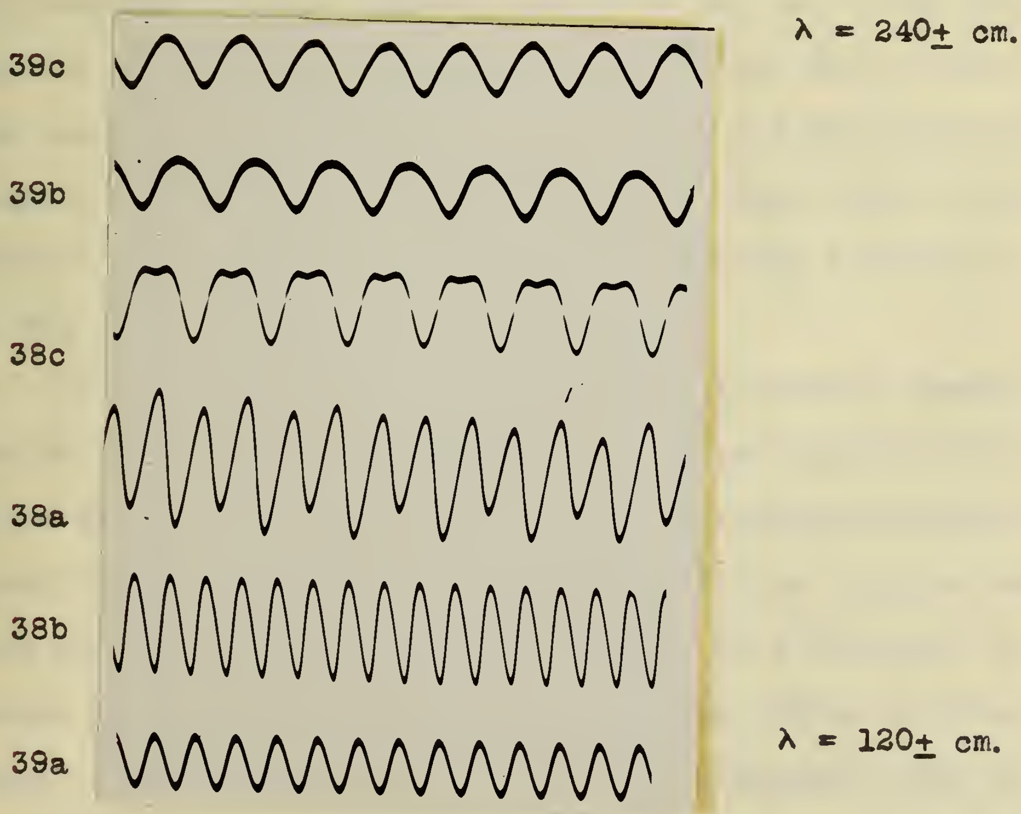


λ = 220 cm.

The waves in this series were taken from tube No. 21, branch-form. The water column was adjusted at +23 cm., +15.2 cm., +11.3 cm., +1. cm., and +15.8 cm., respectively. The first three decidedly show the effect of forcing by means of supplying too much energy. Waves 47 and 53 were taken under the same conditions with the exception that only one burner supplied energy to 53. We further see that the overtones grew less marked as the water column was raised. In 46 the energy was supplied 36 cm. from the node and 27 cm. from the loop, while in 44, which is almost a sine wave, the same two distances are 14 cm. and 27 cm. respectively.

Series III

L-Form; Long Resonator



This most interesting series was taken of sounds emitted by branch tube No. 9 with Resonator No. 12 attached. This resonator was very long but had a small diameter; hence it was impossible from the data at hand to accurately determine the wave lengths represented. They probably range in approximately equal steps for λ_{39c} = 240± cm. to λ_{39a} = 120± cm. For wave 39c, the water column was adjusted +18 cm. A disturbance in the top of the wave can be readily seen. From the next two waves with the water column at +13 cm. and +6 cm., one can see that the disturbance has grown and that an overtone having plenty of energy has made its appearance. In 38a, water column at +1 cm., the disturbance has grown so that it dominates the whole form. A study of the curve will show that one wave was creeping up on the other, causing peculiar maxima and minima which produced a deep rumbling sound to the ear. For the last two waves the water column was adjusted at -4 cm. and -6 cm. These waves are pure sine waves probably due to the fact that the supply of energy was close enough to the node to make only one length of vibration possible. For 39a the energy supply was only 4.5 cm. from the node.

It has long since been noticed that certain branch tubes sounding their fundamentals vary their tones slightly with the movement of the water column until the water reaches a certain critical height. At this point the tone changes with a rasping break, to a higher pitch. This break is accompanied by a decrease in air pressure over the water, causing the water column to rise suddenly several centimeters. The new tone with a decided rise in pitch then persists for any water level above this critical point. If we lower the water level the higher tone persists until we reach a

point two or three centimeters below the first critical point, when a break in the tone will again occur and a sudden increase in air pressure over the water will be noted. This phenomena can be explained by the new theory for operating conditions brought out in this paper as follows.

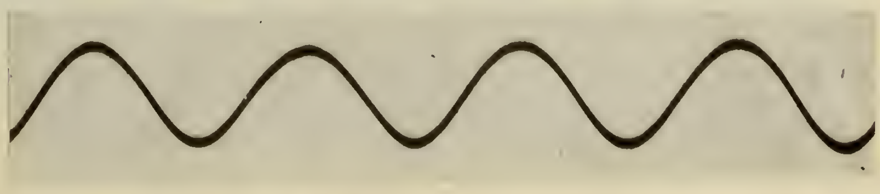
When the tube starts to sound a quarter wave length having properties compatible with the dimensions of the various vibrating columns, is set up in a condition of stable equilibrium which exists only so long as certain critical proportions as regards the dimensions of the various columns do not exist. When the water piston is raised it finally reaches a point where these critical proportions exist and the wave is unstable. As the piston passes this critical point the old wave is destroyed and a quarter wave length having different end corrections and different pressure distribution as regards the various vibrating columns, is again set up with stable equilibrium, as was described on page 9. When the water level is being lowered through the critical point the condition as described above is reversed.

As is described in the discussion for Series 4 and 9, a resonator on the singing tube acts much the same as an inductance in an electric circuit. This causes the adjustment from one stable vibrating condition to another to take place gradually. Series 3 shows this adjustment in its various steps.

Series No. IV

Branch-Form, Resonator, One Burner

25k



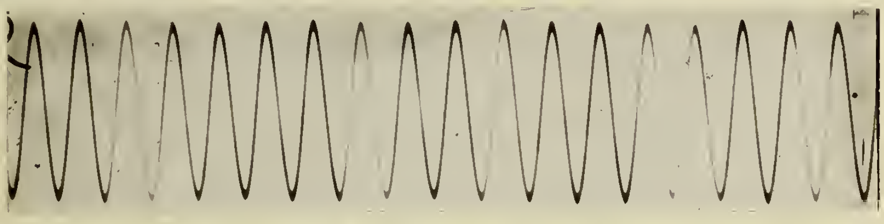
λ = 202 cm.

This curve of wave length approximately 202 cm., was taken from tube No. 9 branch form, with one burner supplying energy. The water column was adjusted to +12 cm. which caused the energy to be supplied approximately 22.5 cm. fron the node and 28 cm. from the loop. Resonator No. 10 was used. The curve shows a very slight flatness on top, probably due to the fact that the resonator has smoothed out an overtone somewhat like the one in wave No. 46 Series 2.

Series V

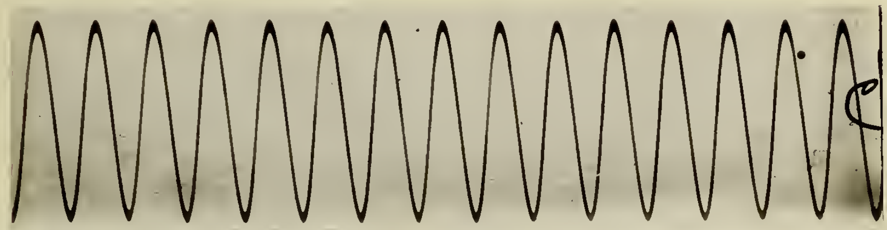
Straight-Form, Without Resonator, One Burner

32a



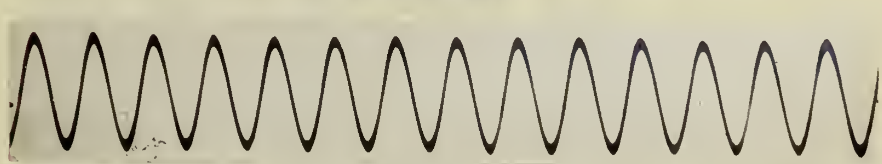
λ = 123 cm.

34c



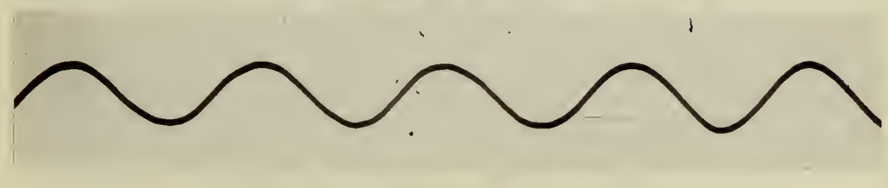
λ = 179 cm.

35c



λ = 205 cm.

1



λ = 215 cm.

This series shows four waves selected from a long series taken with tube No. 5, straight form. These waves are all pure sine curves and represent wave lengths of 123 cm., 179 cm., 205 cm., and 215 cm., respectively. Extensions with carefully ground ends of the same diameter as the tube were added to produce the various wave lengths. The purity of the tone is probably accounted for in three ways; first, the straight form of tube is perfectly symmetrical, second, the energy was supplied in correct quantities, and third, the energy was supplied in the proper place in respect to the wave length. In each wave the energy was supplied at a point 8.1 cm. from the node, while the distances to the loop varied, being for the different waves, 22.6 cm., 36.6 cm., 43.4 cm., and 55.6 cm., respectively.

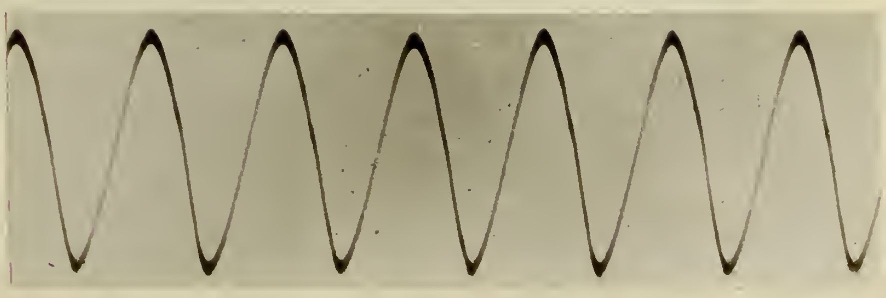
Series VI

Straight Form, Without Resonator, Energy Effect

58

λ = 148 cm.

59



λ = 148 cm.

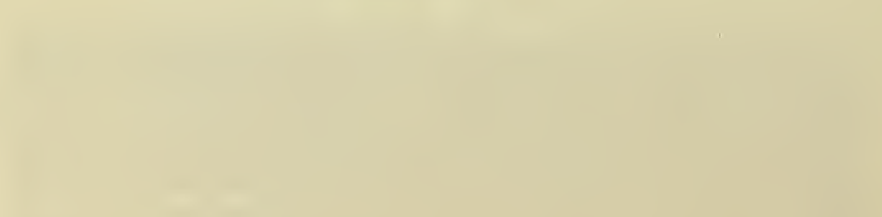
[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

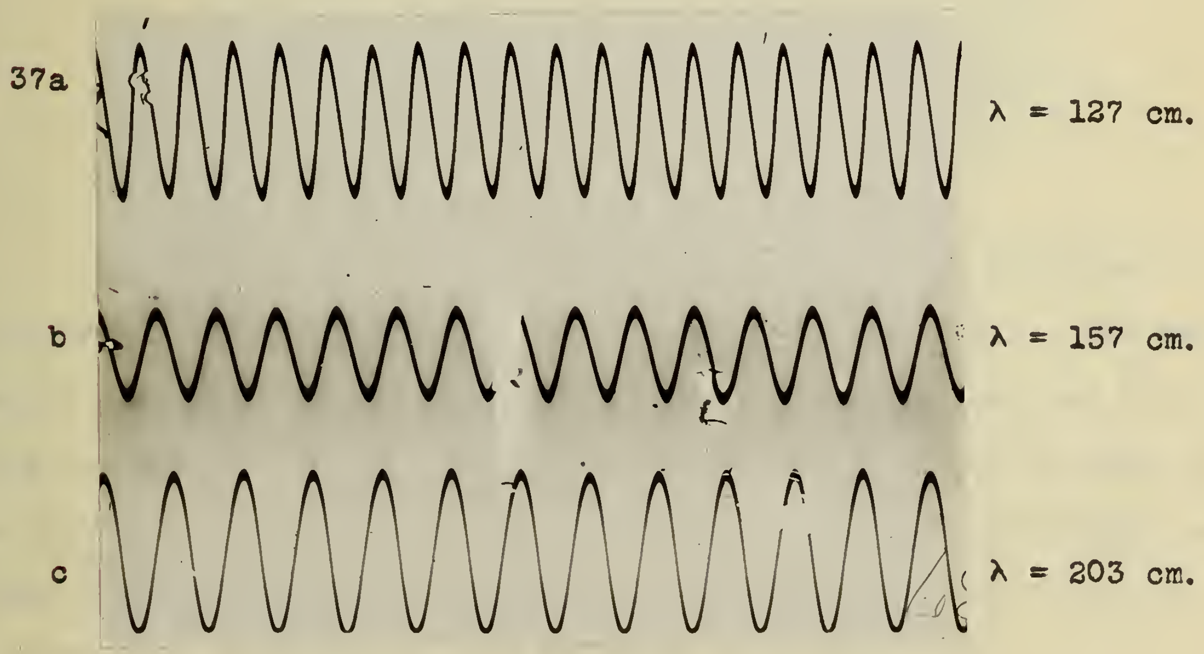


[illegible]

These waves from tube No. 14, straight form, were taken under identical conditions except that the energy for wave No. 58 was supplied by one burner, while the energy for No. 59 was supplied by two. Wave No. 58 is a pure sine curve while the crests of 59 are flattened. In addition, each maxima in 59 shows, on the right hand side, a suggestion of an overtone about one third of the way down from the crest. This is obviously due to forcing produced by supplying energy at a too rapid rate. These two photographs suggest very loudly that the tone-energy relation is very important and should be investigated further. The wave length for both is 148 cm., and the energy was supplied 9.7 cm. from the node and 27.3 cm. from the loop.

Series VII

Straight-Form, Resonator, One Burner



The conditions under which this series was taken were identical with those described in Series V, except that Resonator No. 11 was here attached to the singing tube. These waves are all pure

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

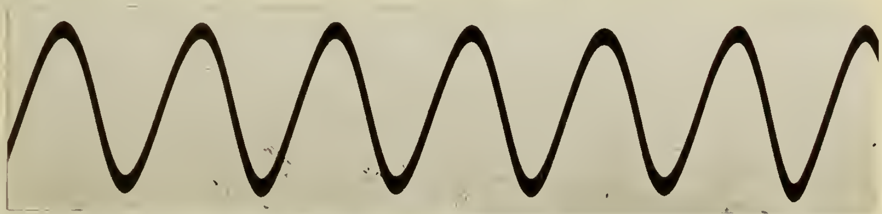
[illegible]

sine curves. The very bottom of wave c was cut off in photographing it. The wave lengths are approximately 127 cm., 157 cm., and 203 cm., respectively. The energy was supplied in each case 8.1 cm. from the node, and 24 cm., 32.3 cm., and 43 cm., respectively from the loop.

Series VIII

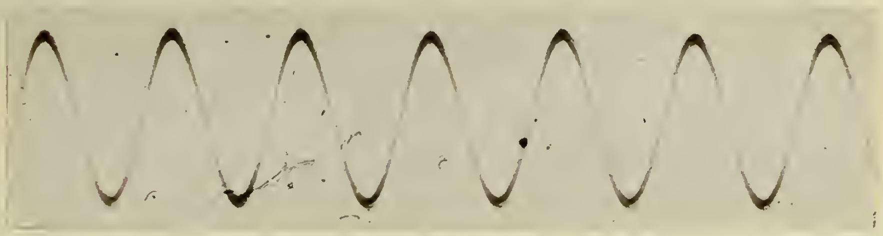
L-Form, Two Diaphragms

54a



λ = 147 cm.

54b



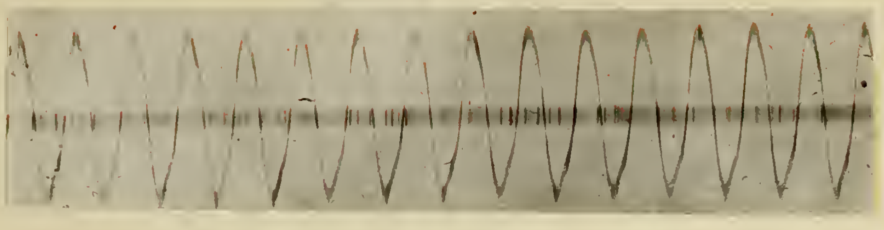
λ = 147 cm.

The two waves in this series were taken under identical conditions, except that two different diaphragms were used. The wave length is 147 cm. and the energy of one burner was supplied 8.1 cm. from the node and 28.6 cm. from the loop. This series was made up to show that the wave form was not a function of the diaphragm used. These waves are pure sine waves, the energy having been supplied at a point most conducive to the emission of a pure tone.

Series IX

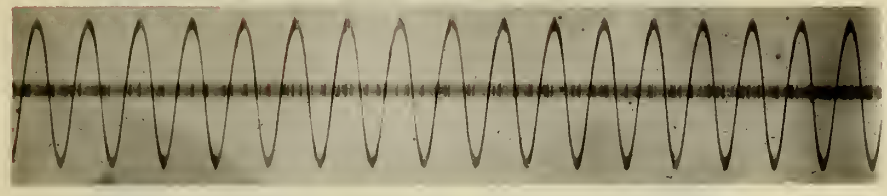
Photographs Taken by Method One

6



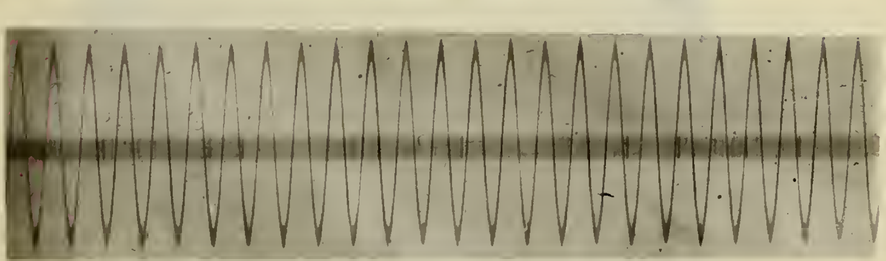
λ = 137 cm.

15



λ = 153 cm.

12



λ = 123 cm.

These three waves represent a long series of photographs taken by Method 1. The wave lengths represented are 137 cm., 153 cm. 121 cm., respectively. Waves No. 6 and 15 were taken from sounds emitted by branch tube No. 4. Wave No. 6, taken under conditions similar to 18c, Series I, shows an overtone at both the top and bottom of the wave. Wave 15 is identical to wave 18c except that the latter was sounding with Resonator No. 1. This again shows that the resonator smooths out the curve by amplifying a vibration of its own frequency and subduing the overtones. Wave No. 12 was taken from a sound emitted by straight tube No. 5 with no extension and no resonator. This wave is identical to Wave No. 32a Series V.

The results from the first method of sound wave analysis check in every detail with the diaphragm method.

[illegible]

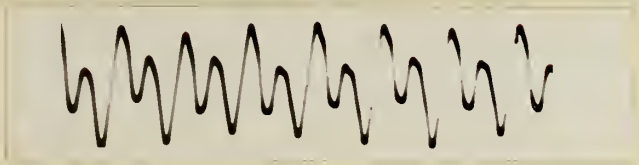
[illegible]

[illegible]

Series X

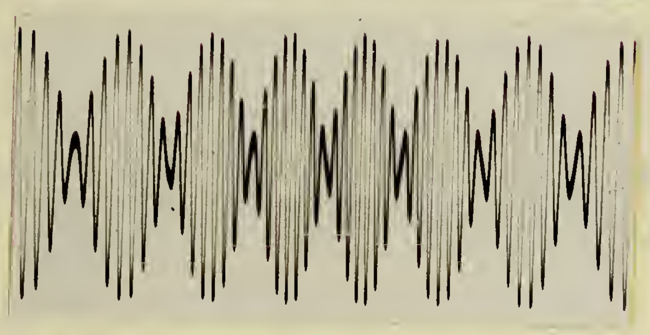
Miscellaneous Wave Forms

A



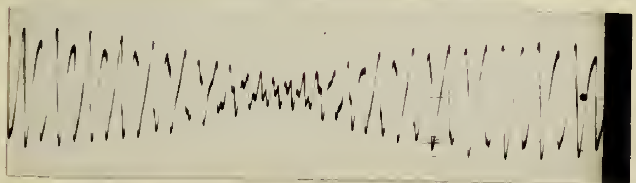
B

C



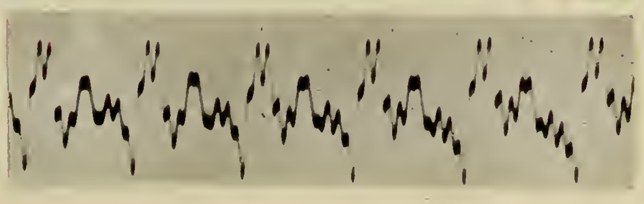
D

E



F

G



This is a series of curves taken by method two to show that the diaphragm as used was sensitive to even the faintest overtones. Wave A is the sound wave of an open organ pipe. Several overtones can be found in the wave. Wave B represents the sound wave produced by two tubes sounding together, an L-form and a straight form, no resonator being used on either tube. This wave demonstrates the ease with which the dermatype diaphragm followed a complex wave form. At least six wave forms can be traced in this curve.

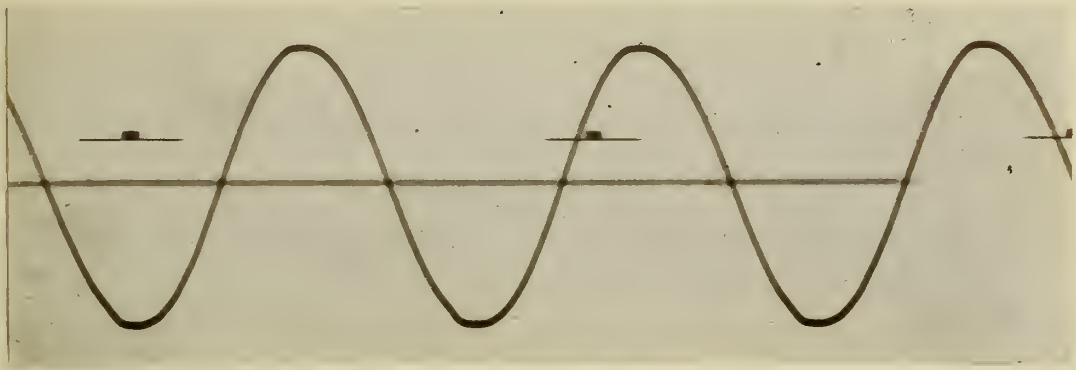
Waves C, D, and E were taken by Professor Knipp during the author's absence. In C the two L-form tubes used were adjusted to each give its maximum tone with a resonator attached. The two tubes were companion tubes and when adjusted each to its maximum, they proved to be nearly in tune. A slight adjustment of either gave any desired beat frequency. This curve is exceedingly clear cut and bears a critical study under a glass. For each tube the energy was being supplied by one burner, hence the components of the wave should be nearly pure sine waves. An uniform motion of the film makes the beats appear to be of different sizes. In D the same two tubes were adjusted to nearly unison, giving six or seven beats per second. The other conditions were the same as in C. In E there was superimposed upon D the tone emitted by a high pitch organ pipe blown to sound its fundamental. The film was moving some faster, otherwise the conditions were the same. Wave F was taken from three open organ pipes sounding together. The pipes ranged from a very low to a very high pitch and were being blown with considerable pressure so as to produce overtones in each one. This is not a hap-hazard curve as it appears at first sight, but

rather an ordered succession of a single configuration, three of which appear on the photograph. Wave G represents a note from a French horn. The wave forms represented in B, E, F and G, should remove from the minds of even the most skeptical any doubt as to the sensitivity of the diaphragm and the validity of method two.

Series XI

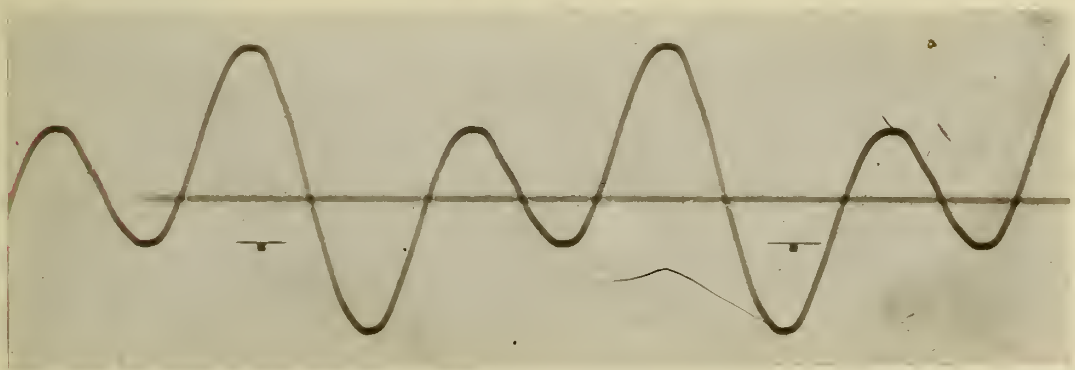
Photographs by Professor D.C. Miller

2260



λ = 256 cm.

2261



λ = 284 cm.

These two photographs were taken by Professor D.C. Miller with his phonodeik, of sounds emitted by the L-form of tube. The water columns were adjusted to +11.2 cm. and +16.2 cm. respectively, which caused a wave length of λ_{2260} = 256 cm., and λ_{2261} = 284 cm., to be produced. The slight indication of a higher octave in each maxima of 2260 is similar to that before noted in 18c Series I.

Photograph 2261 shows only two complete wave lengths, hence it is difficult to find out just what was happening. Two waves cut from the right end of No.38a Series III, show the same type of wave form, while the curve taken as a whole reveals a phenomena which could not even be guessed by considering two waves only. The same can be said of A, Series X. Wave No.46, Series II, would probably show the same form as No.2261 if carried to a wave length equal to the latter. Nothing further is known of the conditions under which the two waves in this series were taken or of the dimensions of the tubes used.

GENERAL DISCUSSION

It is evident that this investigation has opened the way for, and pointed out, the direction to be taken in a large amount of subsequent work which must be done on these singing tubes, before accurate statements can be made regarding their merits as "A New Standard of Sound".

The tone produced is a function of several complex things. Although it is known that a tube of this kind "to sound its fundamental with ease must have definite length as regards the various vibrating columns"; to date, but little is known as to how these lengths are affected by their respective cross-sections, and only approximate knowledge is at hand regarding the ratios of the various lengths.

Most L-form tubes will not sound when the branch and stem are both open; however, tubes have been constructed with both ends open which sounded. Every tube appears to have a point to which the water piston must be adjusted before it will produce the largest volume of sound. This point varies with the other dimensions.

The exact effect of the quantity of heat energy applied is also an unknown. Tubes have been constructed that sounded when one

gas ring burner was applied, and others even refused to sound at all when urged by the energy from two ring burners.

The point of application of the energy in regard to the wave length has been approximately determined but the position of this point as a function of the upper opening or lips of the column, See Fig. 4) is unknown. A slight movement of the burner has been known to change very markedly the pitch of the tone emitted. The effect of the thickness of the lips and the shape and volume of the cavity above them, are problems that have scarcely been touched, while the question of the best ratio of the respective cross-sections of the column to the annular ring needs more investigation.

In the work just completed no account has been taken of either the muffling effect of water vapor above, or the unstable surface of the water piston.

As was mentioned before, as yet no hard and fast conclusions can be drawn as to the worth of these tubes as standards of sound. Curve 54b has been presented as a pure sine wave from the L-form, and although this was obtained with great difficulty, if one knew the effect of the different variables just discussed, and how to manipulate them to advantage, pure tones might be forthcoming with ease. At the present time, however, if supplied with a correct amount of power from a constant source, the straight form might, in the judgment of the author, be used with success as a secondary standard.

CONCLUSIONS

From the work just presented the following conclusions can be drawn.

1. The operating conditions are given by Figs. 6a and 7a,

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

which show that the total length from the node to the open end of the tube corresponds to one quarter of a wave length. This accounts for the low tone that the tube emits when sounding.

2. A pure tone can be obtained from the L-form of singing tube by a correct adjustment of the lengths of the various vibrating columns, but it is extremely difficult to get.

3. A pure tone can be very easily obtained from the straight form of singing tube if the column is approximately one half the length of the tube or less.

4. The rate of the supply of heat-energy has an effect on the purity of the tone emitted. Too great a supply of energy introduces overtones.

5. The point of application of the energy supply with reference to the one fourth wave length within the tube affects the purity of the tone produced. The position for purity must be approximately one-twelfth the wave length or less, from the node.

6. Resonators used with the singing tubes tend to damp out overtones.

In conclusion the author wishes to express his thanks to Professor Knipp, whose discovery of this form of singing tube made the foregoing investigation possible, for the abundant supply of tubes, and for his direction of and interest in the work; and to Professor Carman for the facilities of the department.